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International Center for
Air Transportation

Potential Safety Benefits of RNP Approach Procedures

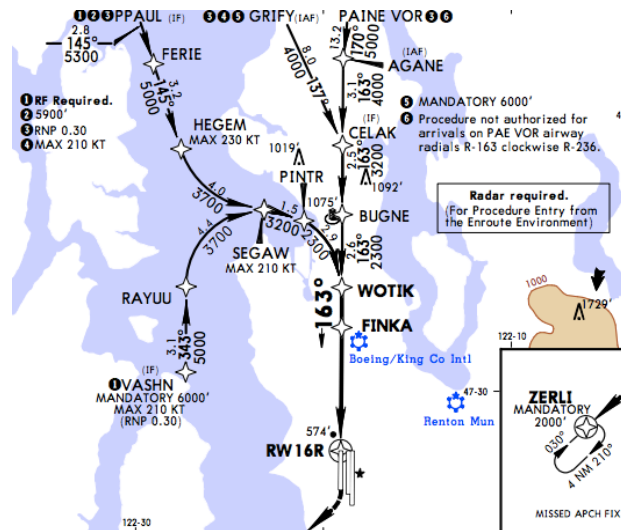
Sandro Salgueiro

Advisor: John Hansman

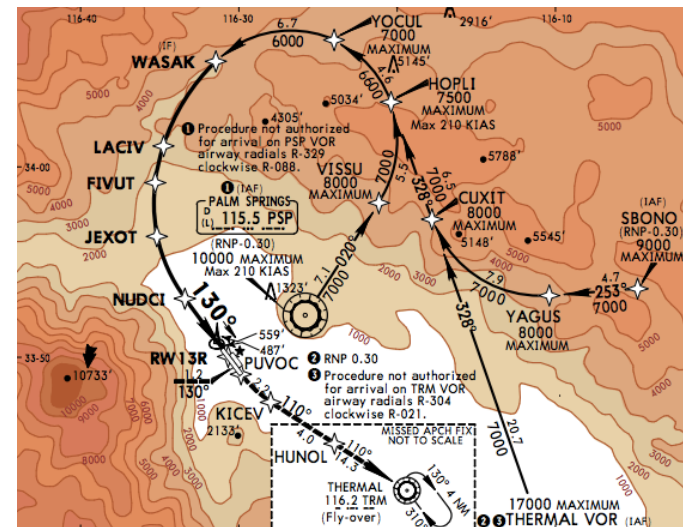
Technical Monitor: Joseph Post, FAA

Potential Benefits of RNP

- Lower approach minimums in areas with challenging terrain.
- Shorter path length.
- Lower fuel consumption.
- Less noise over populated areas.
- Increased safety.
 - Lower probability of unstabilized approaches.



KSEA RNP RWY 16R



KPSP RNP RWY 13R

Approach Stability and Safety

- Unstable approach:
 - Too fast/too slow.
 - Too high/too low.
 - Not properly aligned with the runway.
 - Aircraft not in landing configuration.
- Unstable approaches were a factor in 66% of 76 landing accidents and incidents worldwide between 1984 and 1997 (*Flight Safety Foundation*).
- Statistically, unstable approaches increase the likelihood of events such as **controlled flight into terrain (CFIT)** and loss-of-control (LOC).



Elements of a Stabilized Approach

Flight conditions	Must be stabilized below*	Allowed speed deviation	Maximum allowed altitude deviation	Maximum allowed descent rate
VMC	500 ft AGL	$V_{REF} \leq IAS \leq V_{REF} + 20 \text{ kt}$	$\pm 60 \text{ ft}$ from glideslope (<i>one dot deviation</i>)	1000 ft/min
IMC	1000 ft AGL	$V_{REF} \leq IAS \leq V_{REF} + 20 \text{ kt}$	$\pm 120 \text{ ft}$ from glideslope (<i>one dot deviation</i>)	1000 ft/min

VMC: Visual Meteorological Conditions
 IMC: Instrument Meteorological Conditions
 AGL: Above ground level
 V_{REF} : Approach reference speed
 IAS: Indicated Airspeed

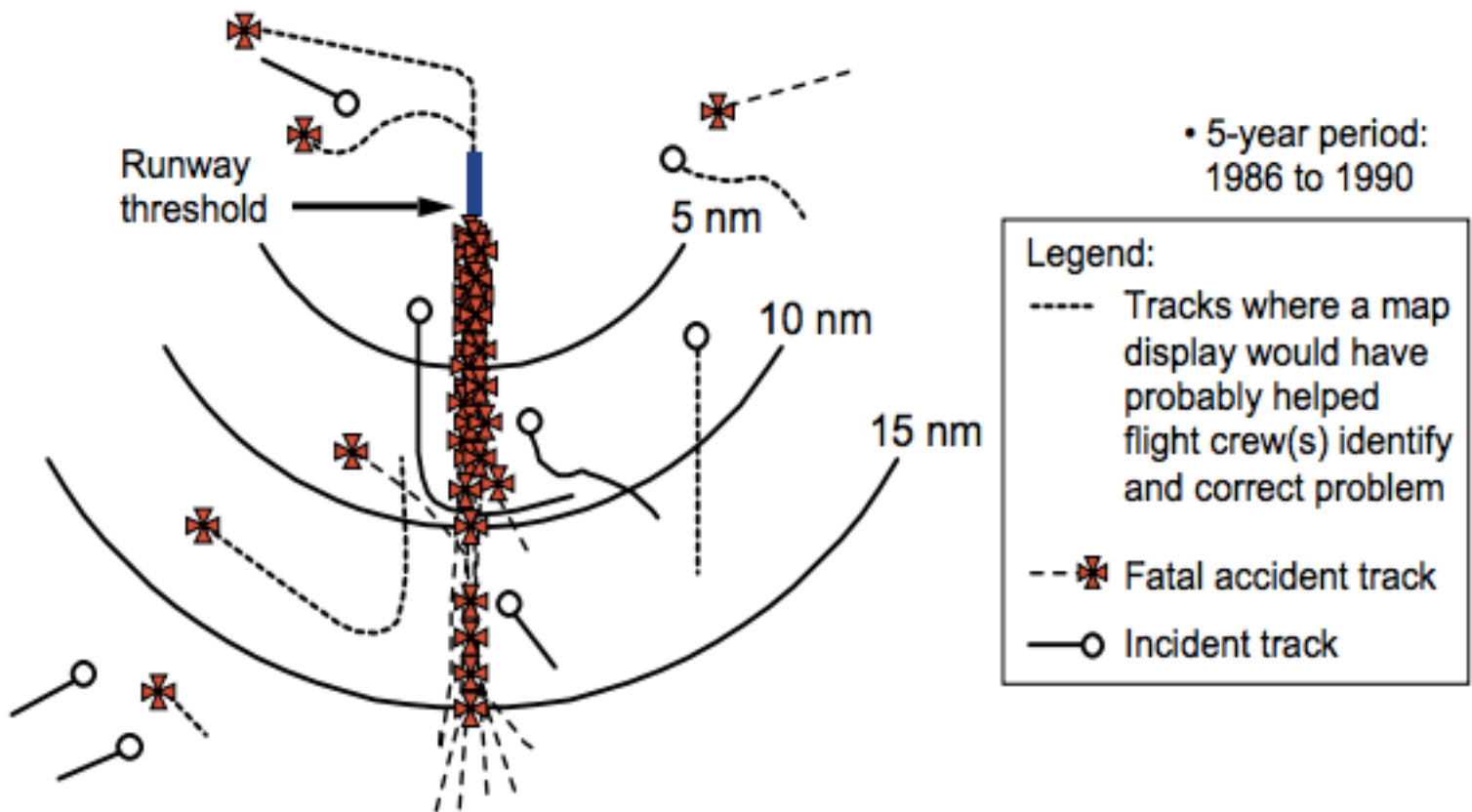
*An approach that becomes unstabilized requires an immediate go-around.

Source: Flight Safety Foundation

Controlled Flight into Terrain (CFIT)

- More than 2/3 of all CFIT accidents are the result of altitude error or lack of vertical situational awareness.

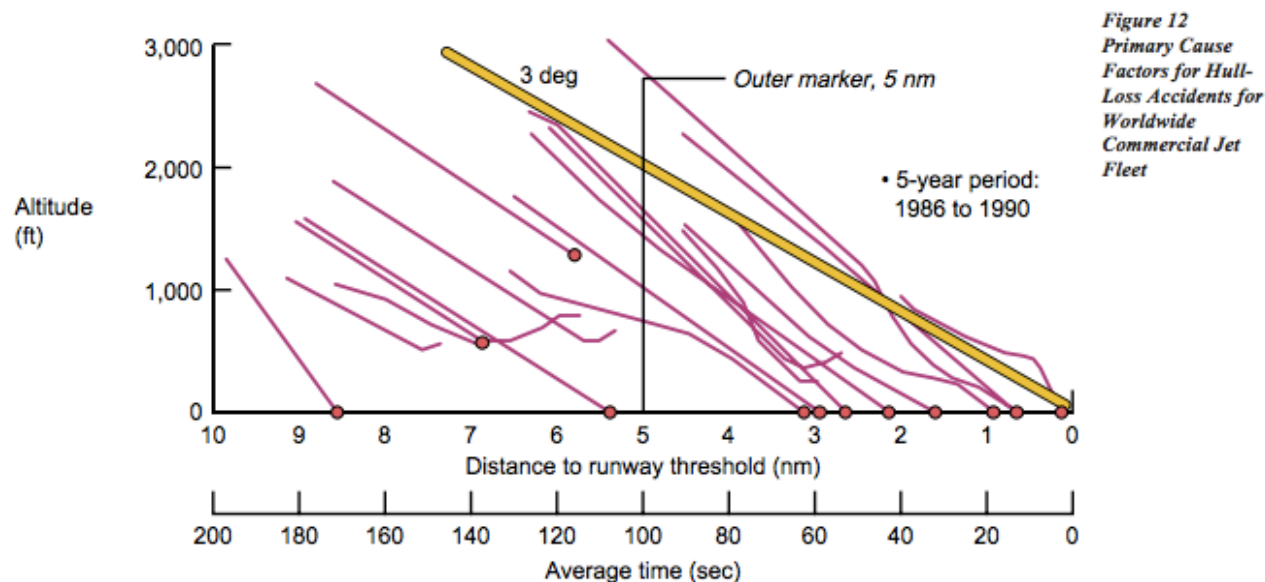
Figure 11
Map Location of
CFIT Accidents/
Incidents



Source: Flight Safety Foundation

Controlled Flight into Terrain (CFIT)

- CFIT accidents are more likely in IMC, darkness, or a combination of both conditions.
- More CFIT accidents occur during non-precision approaches, specifically VOR and VOR/DME approaches.*

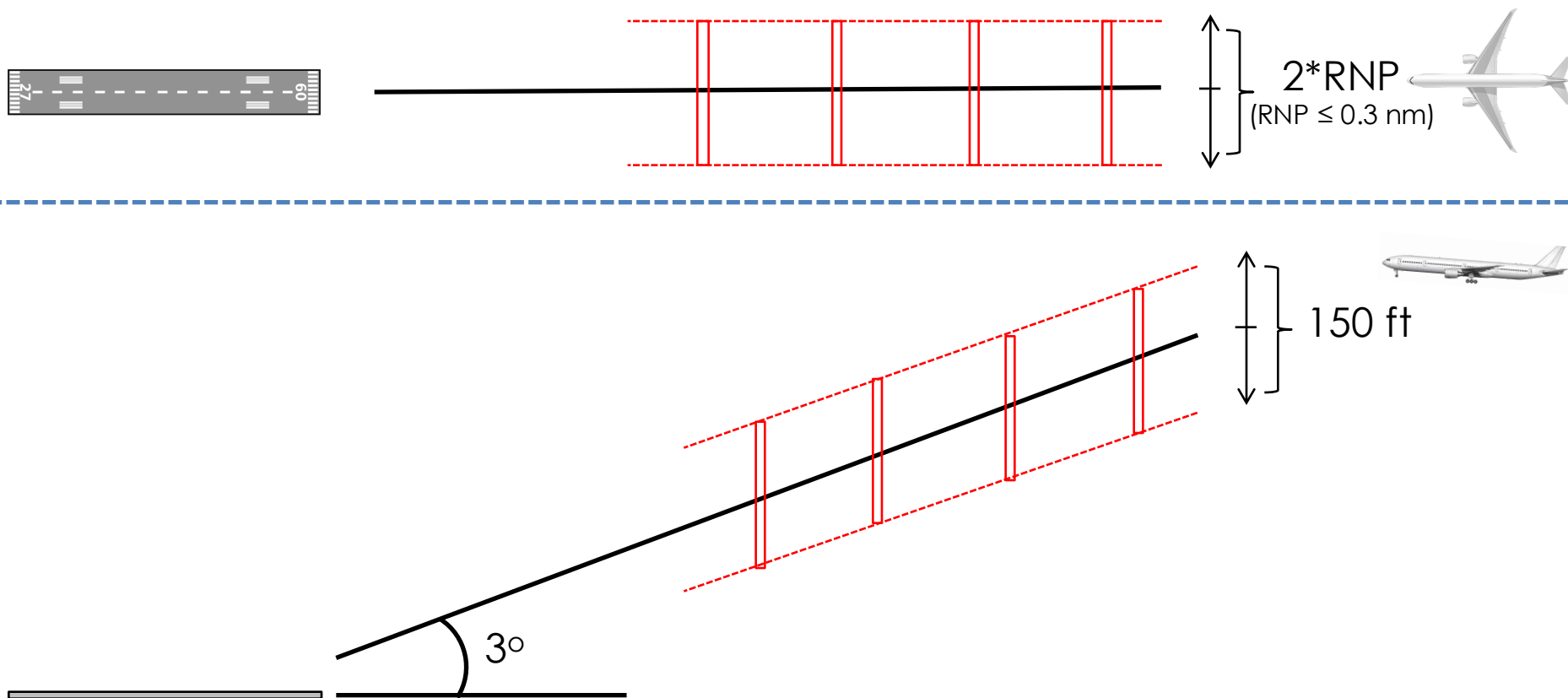


Source: Flight Safety Foundation

*Note: CFIT accidents have been drastically reduced since the implementation of EGPWS.

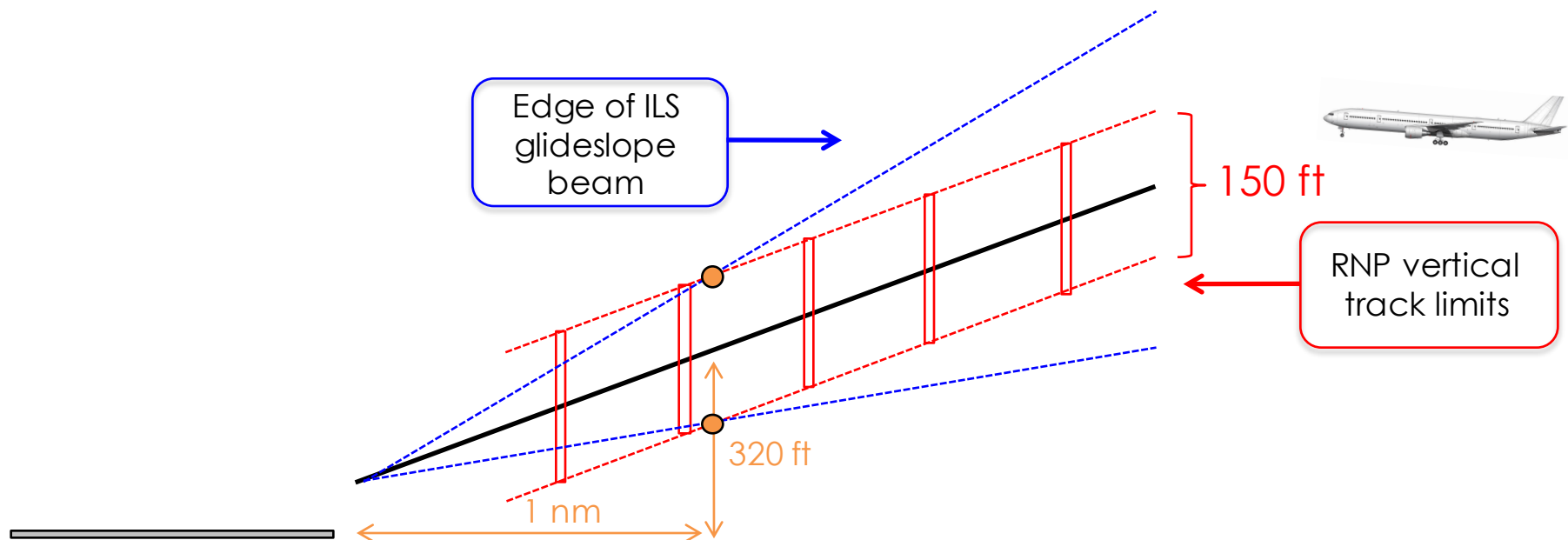
What's different about RNP approaches?

- During an RNP approach, a go-around is advised if either the lateral or the vertical deviation limits are exceeded at any point in the approach.



Comparison: RNP / ILS vertical guidance

- Compared to a conventional ILS approach, an RNP approach offers more precise vertical guidance (higher resolution) at distances **greater than 1 nm** from the runway touchdown zone.
- RNP approaches are usually captured earlier than ILS approaches.



ILS approach vs RNP approach

	ILS	RNP
Vertical guidance?	Yes (angular)	Yes (linear)
Autopilot required?	No	Yes, or F/D
Radio must be tuned and station identified?	Yes	No
Crew alerts for system deficiencies?	Yes, limited	Yes, ANP value displayed
Continued guidance during missed approach?	No	Yes

Hypothesis

RNP may provide improved safety in the following cases:

Existing runway infrastructure

If runway **not** equipped with precision approach (i.e. ILS)

If runway already equipped with precision approach

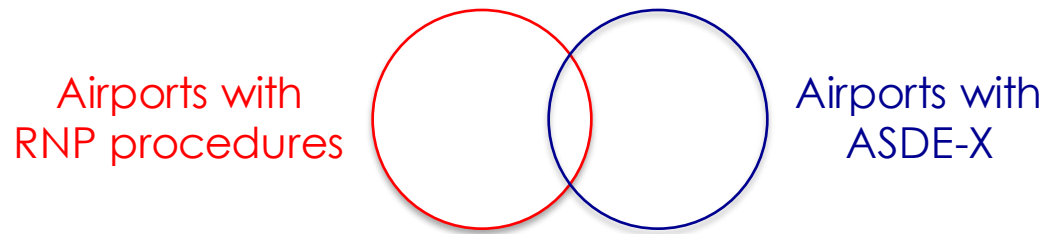
Theoretical benefit

Improved situational awareness
due to vertical guidance

Improved precision, reliability,
and repeatability

Methodology

- ASDE-X data was chosen over terminal radar data (e.g. PDARS) due to its higher update rate (1 Hz for ASDE-X versus ~ 0.2 Hz for terminal radar).
- Airports were chosen based on the availability of RNP procedures as well as ASDE-X surveillance data.



- Analyzed ASDE-X data from **KSEA** (Seattle), **KMDW** (Chicago Midway), **KJFK** (New York JFK), **KDCA** (Washington Ronald Reagan), and **KDEN** (Denver).



Methodology

- Data was analyzed in two rounds:
 - 1st round: analyzed 4 days worth of data from KDCA, KJFK, KMDW, and KSEA; days selected randomly.
 - 2nd round: analyzed 6 days worth of data from KDEN, KJFK, and KMDW; days selected based on knowledge of when aircraft were flying RNP procedures.
- In the data sets, looked for:
 - RNP approaches
 - Potentially dangerous and/or unstabilized approaches
- Looked for potentially improved approach stability in RNP cases.



Data Analysis

Round 1

(4 days from KDCA, KJFK, KMDW, and KSEA)

Total number of arrivals	7,640
RNP arrivals	64
RNP percentage	0.84%

Airport	# of RNP arrivals
KMDW – Midway	59
KSEA – Seattle	5
KJFK – New York	0
KDCA - DC	0

Round 2:

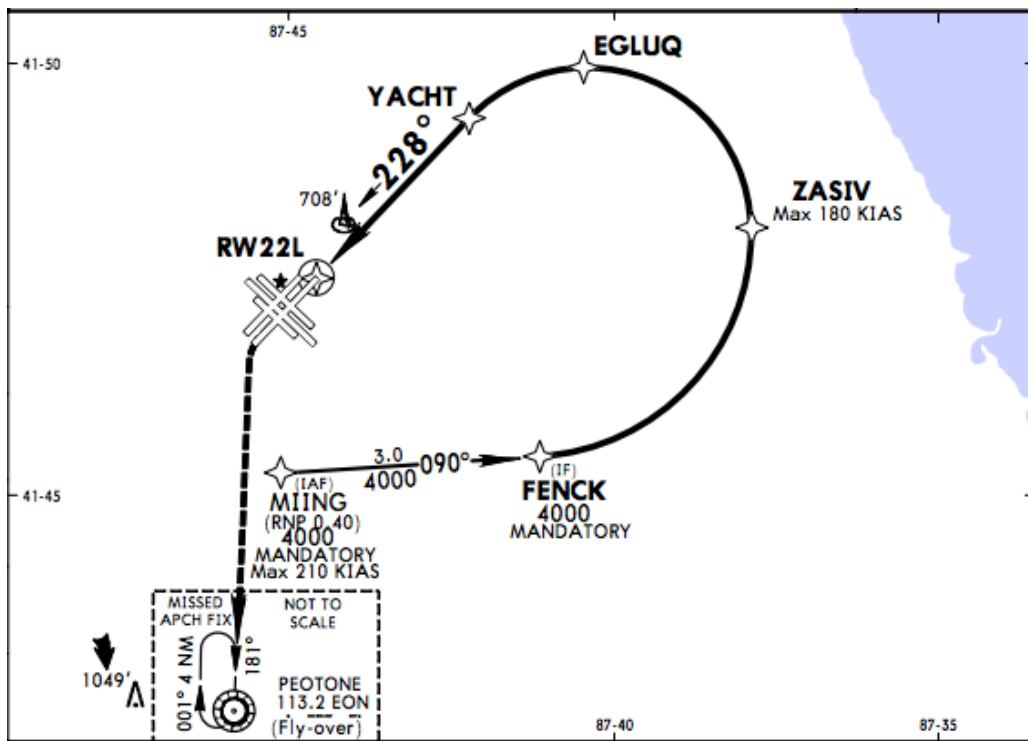
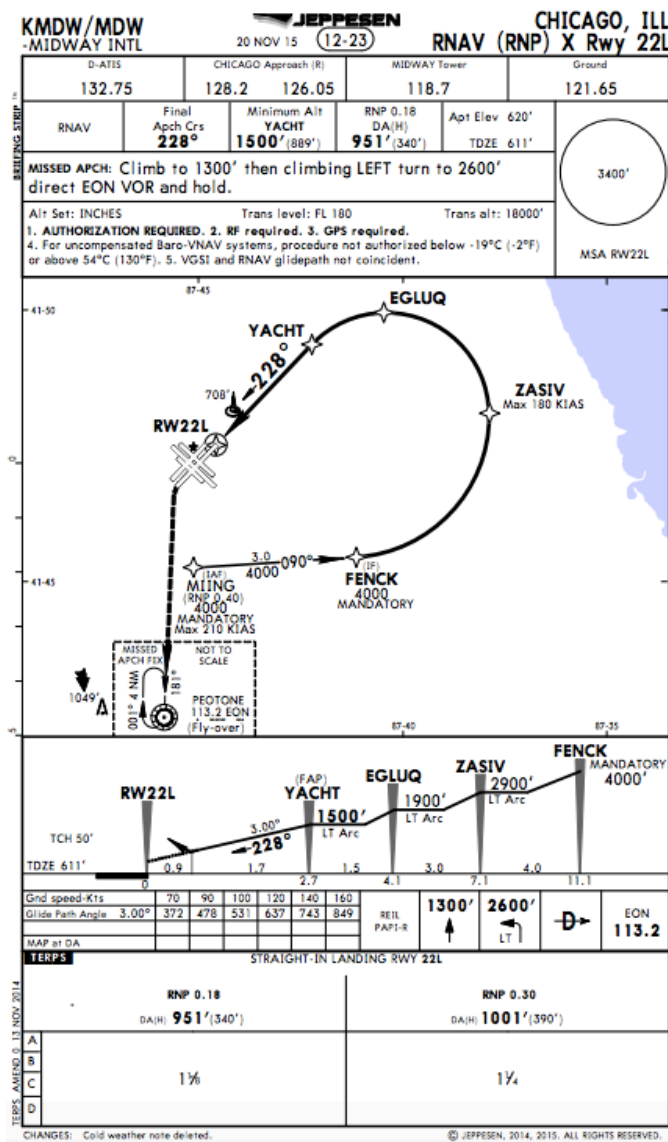
(6 days from KDEN, KJFK, and KMDW)

Total number of arrivals	9,357
RNP arrivals	317
RNP percentage	3.4%

Airport	# of RNP arrivals
KJFK – New York	157
KMDW – Midway	126
KDEN - Denver	34

- Despite high RNP equipage levels among Part 121 carriers (59%), only 381 RNP arrivals were observed.

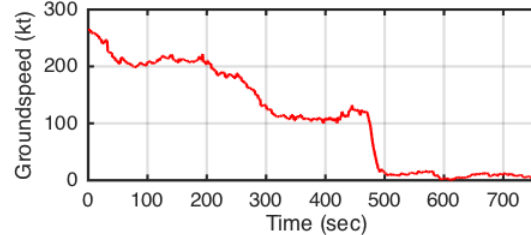
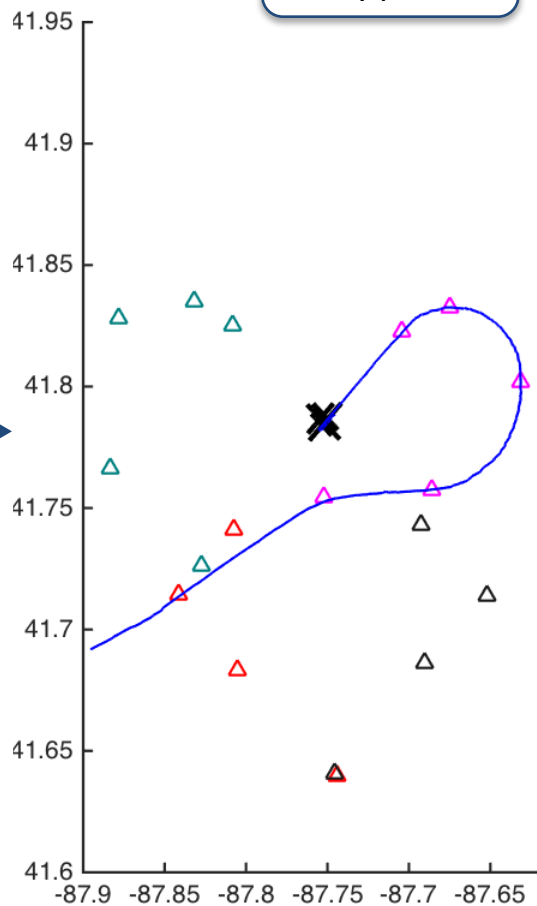
KMDW RNAV (RNP) X RWY 22L



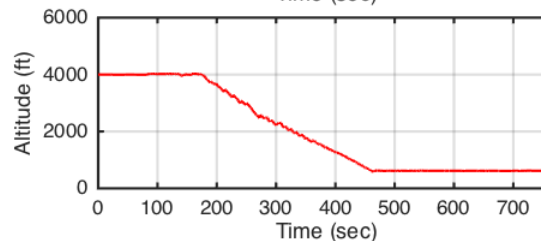
Example Data Sample

Aircraft
type

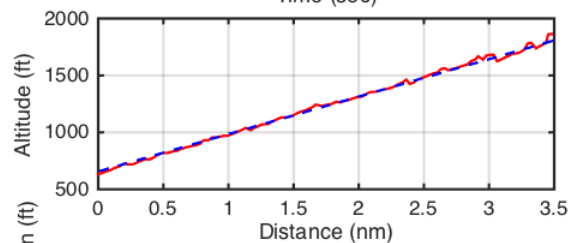
(B737)



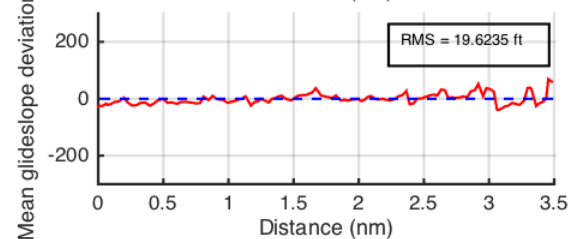
Groundspeed
(kt)



Altitude
(ft)



Vertical
profile
(ft vs. nm)



Glideslope
deviation
(ft)

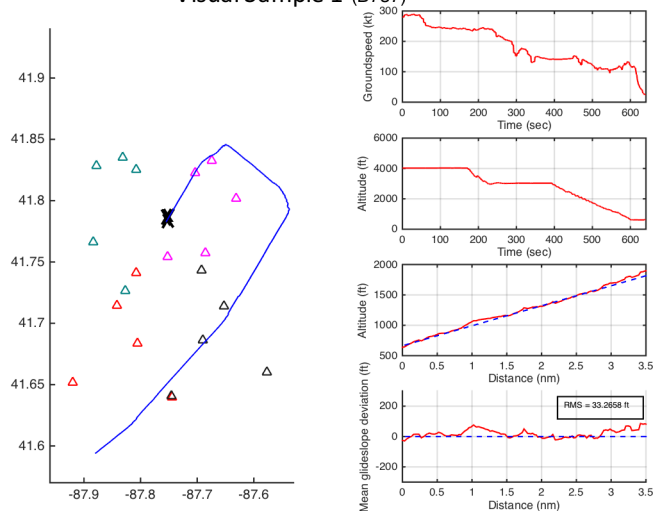
Visual Approach vs. RNP Approach

KMDW (Chicago Midway)
RWY 22L

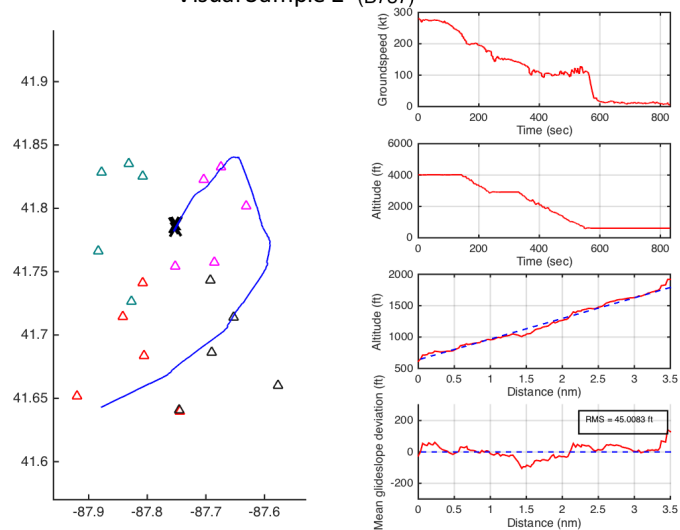
Visual vs. RNP

Visual

Visual Sample 1 (B737)

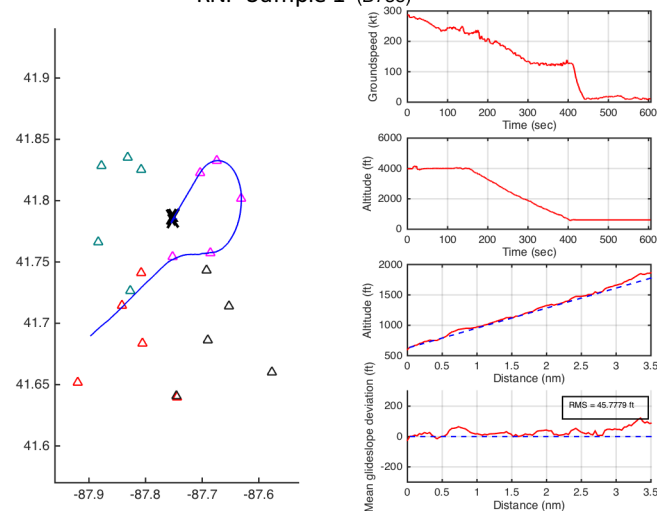


Visual Sample 2 (B737)

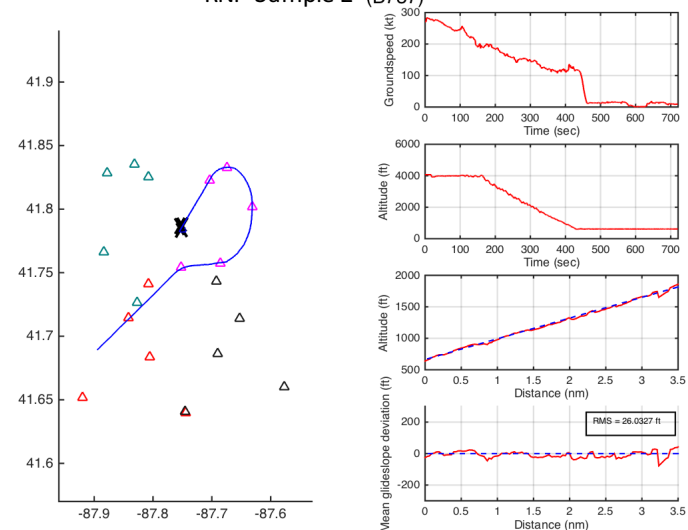


RNP

RNP Sample 1 (B738)



RNP Sample 2 (B737)



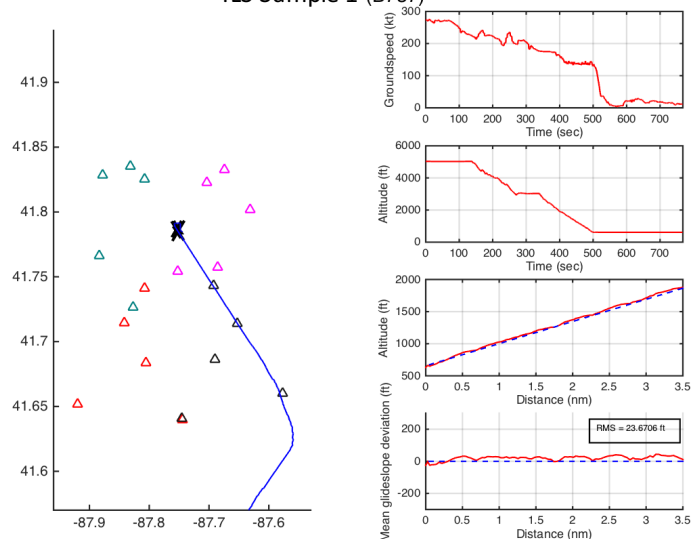
ILS Approach vs. RNP Approach

KMDW (Chicago Midway)
RWY 31C

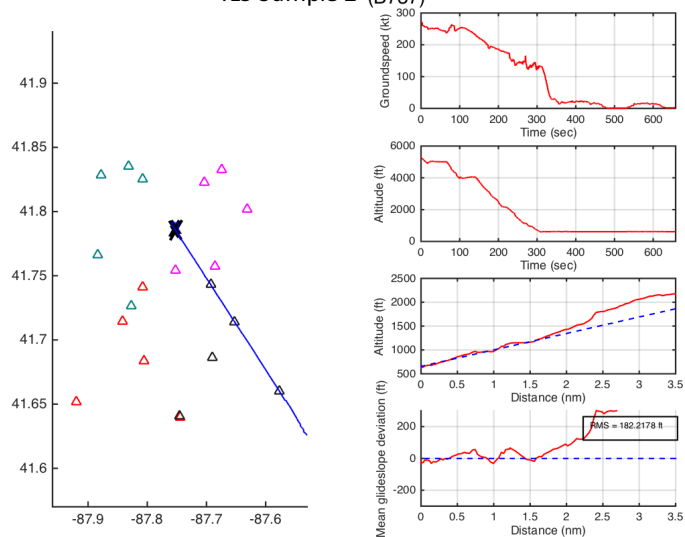
ILS vs. RNP

ILS

ILS Sample 1 (B737)

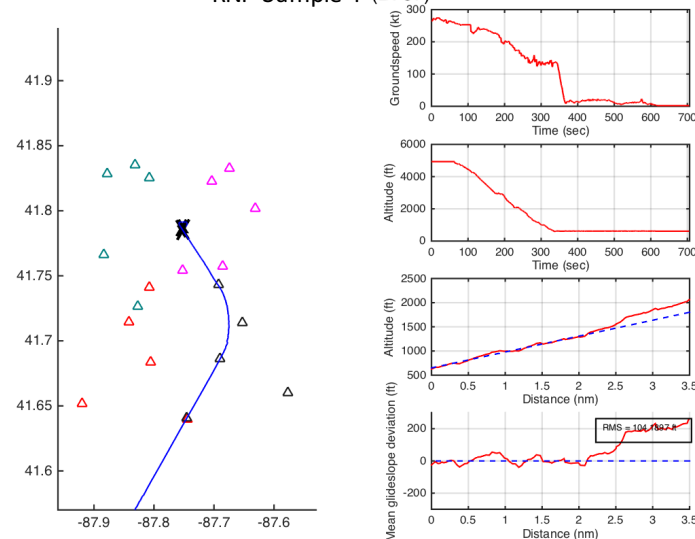


ILS Sample 2 (B737)

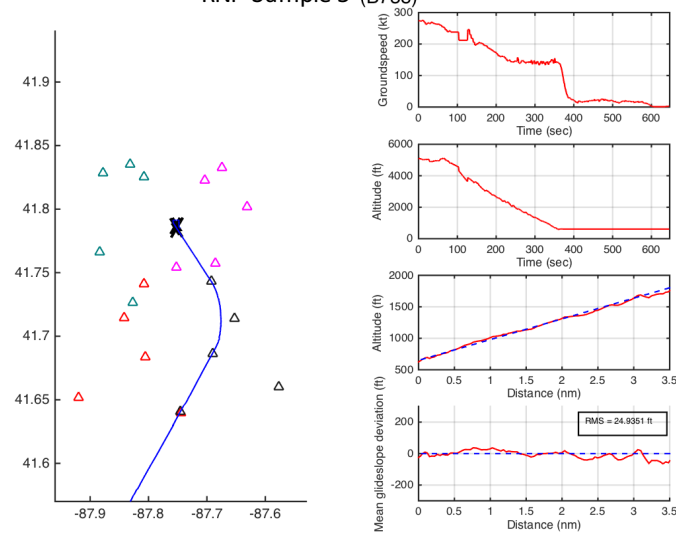


RNP

RNP Sample 4 (B737)



RNP Sample 5 (B738)



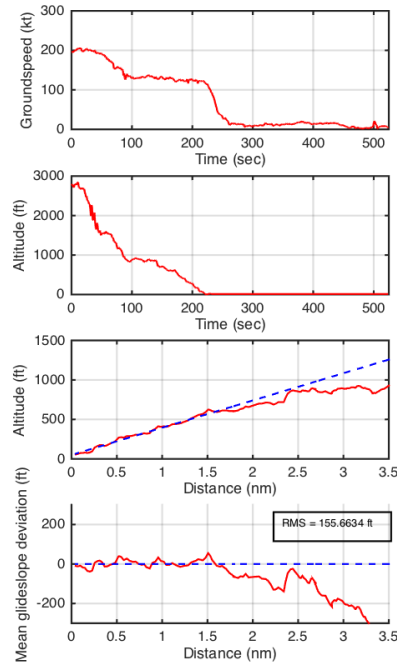
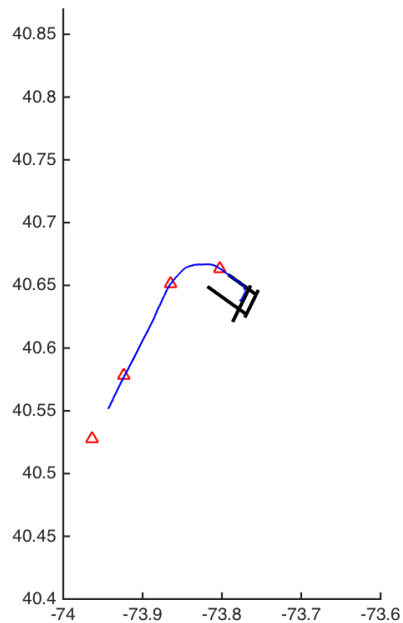
Visual Approach vs. RNP Approach (Canarsie)

KJFK (New York JFK)
RWY 13L

Visual vs. RNP (Canarsie)

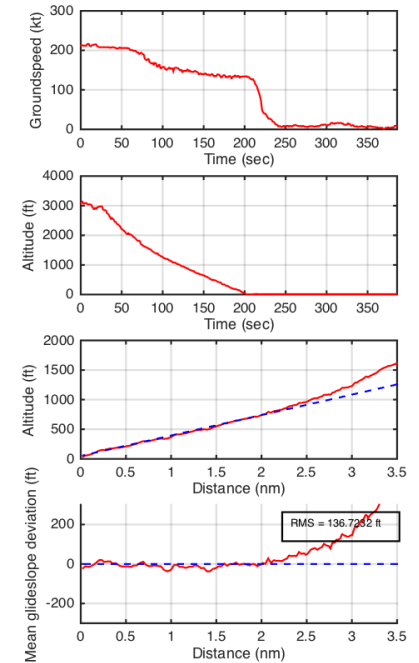
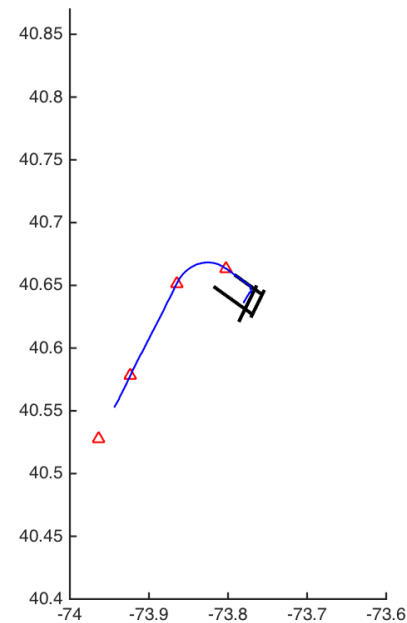
Visual

(CRJ9) - 2016-02-03



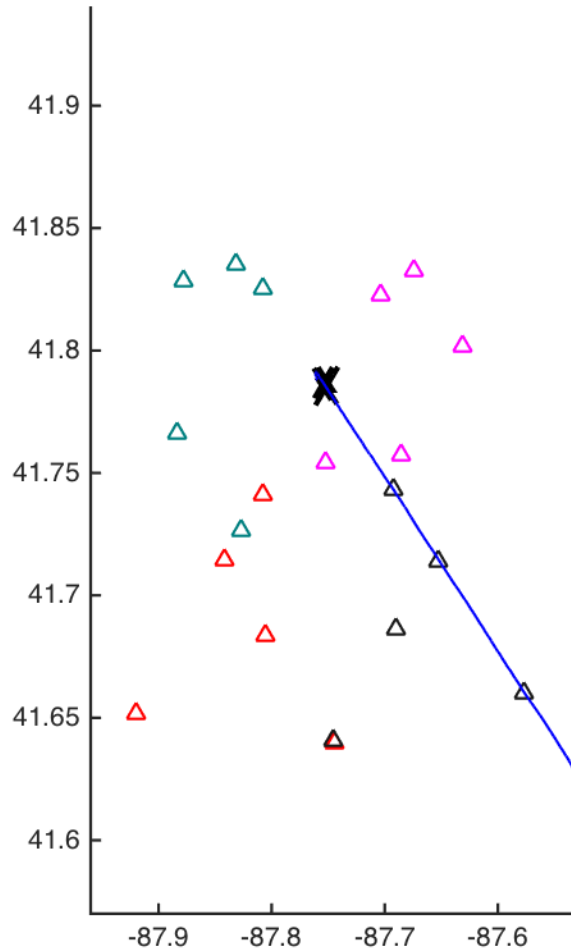
RNP

(A320) - 2016-01-26

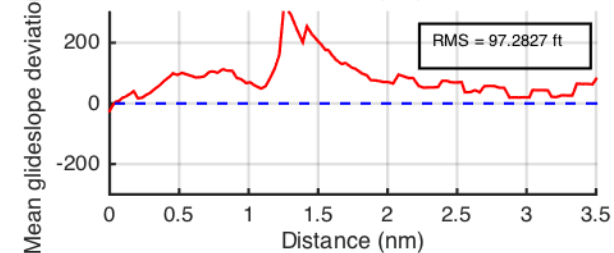
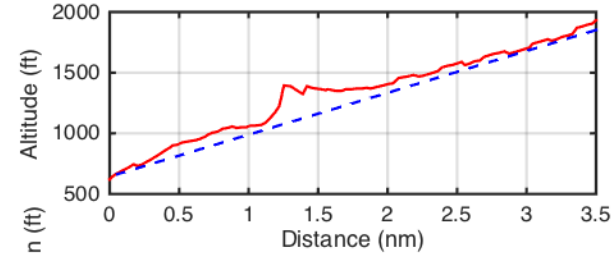
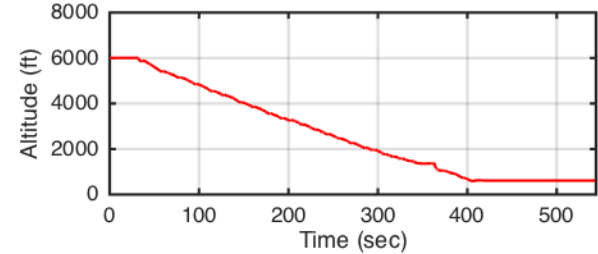
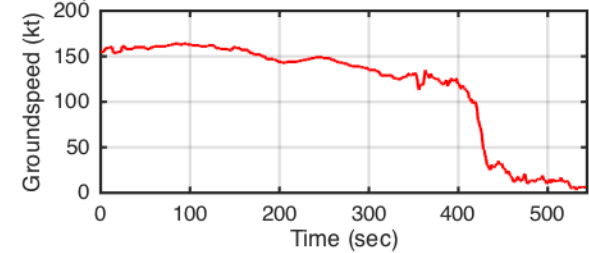


Other Interesting Cases

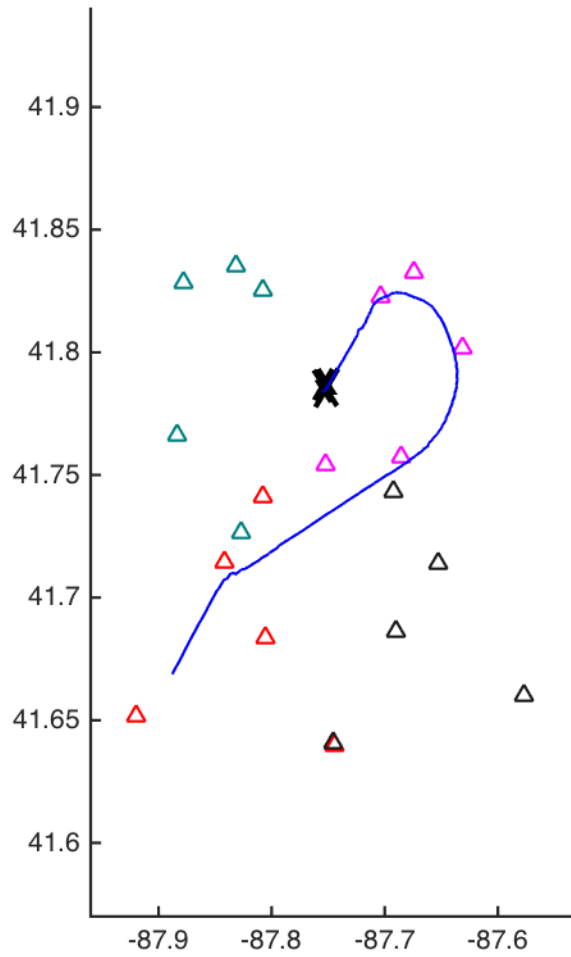
Citation loses glideslope



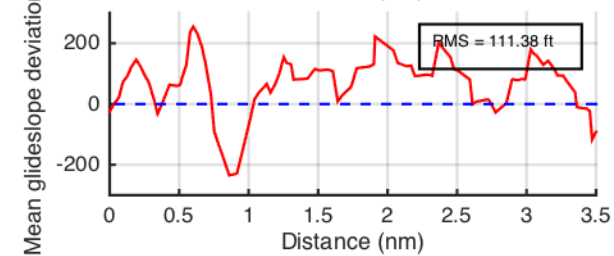
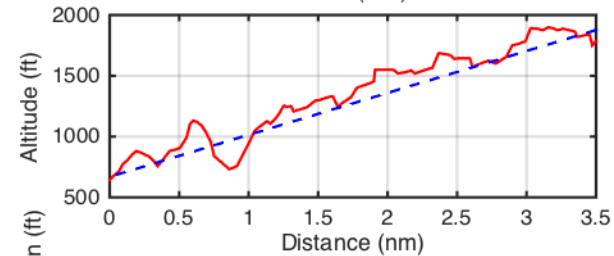
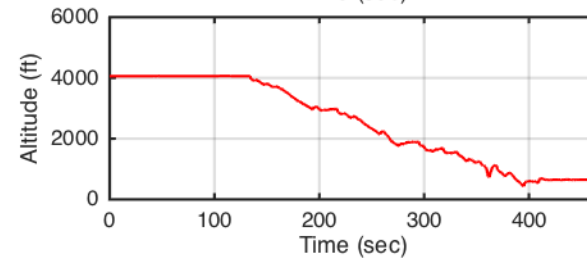
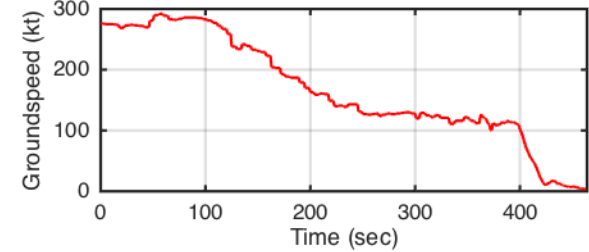
(C56X)



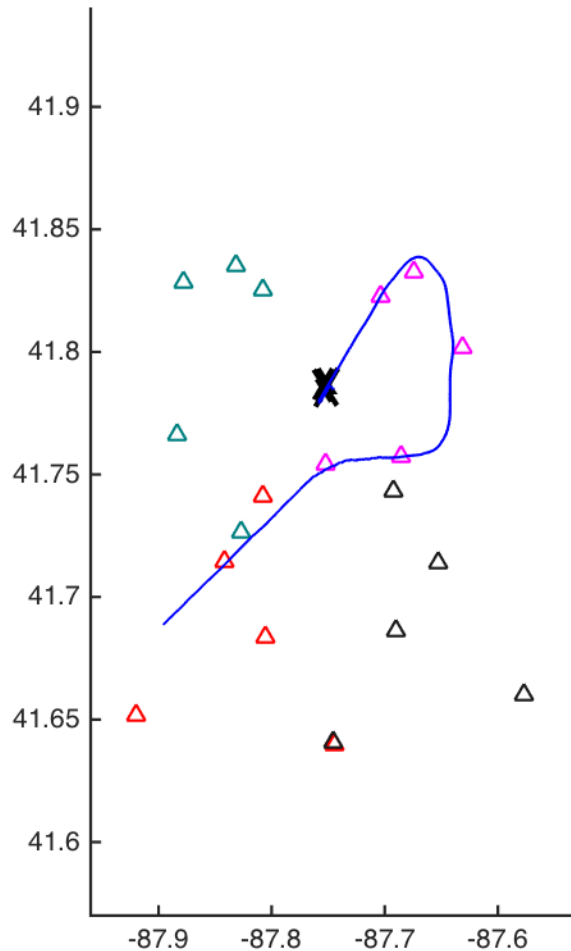
Learjet “all over the place”



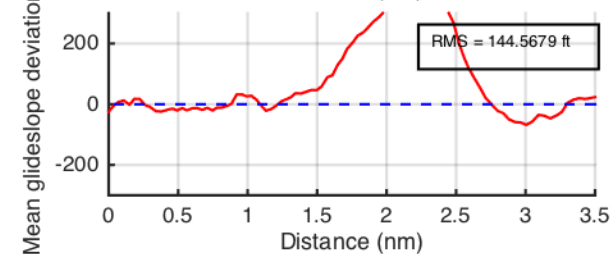
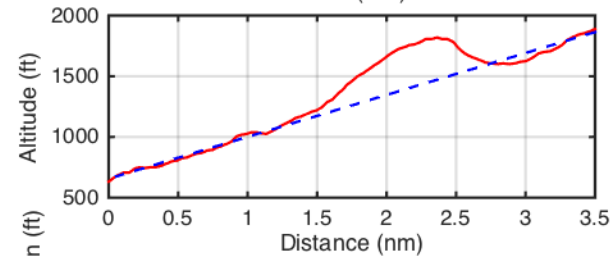
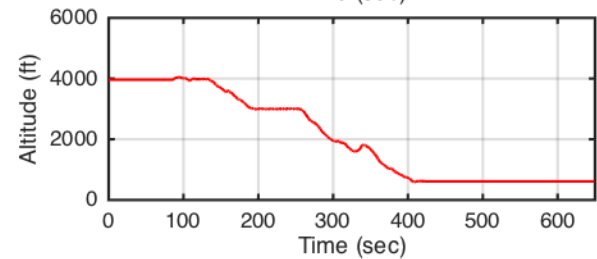
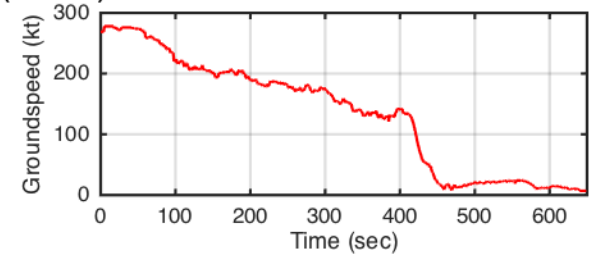
(LJ55)



B737 starts climbing on final

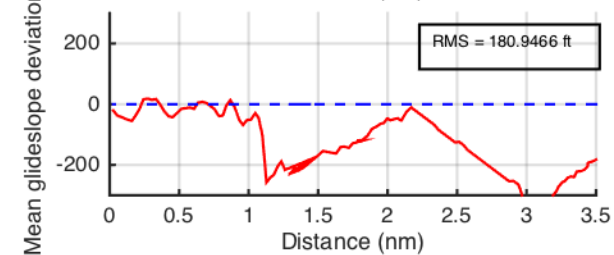
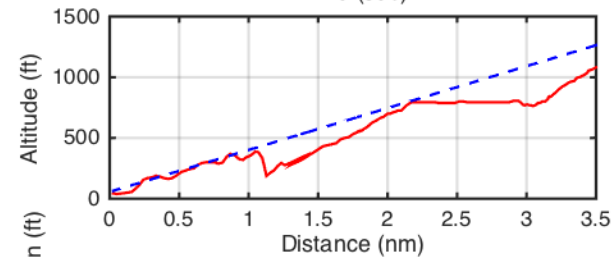
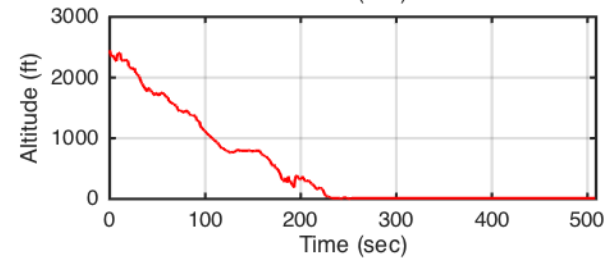
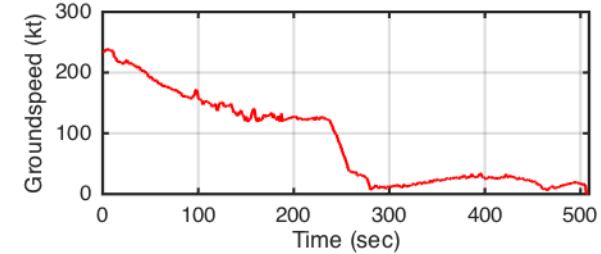
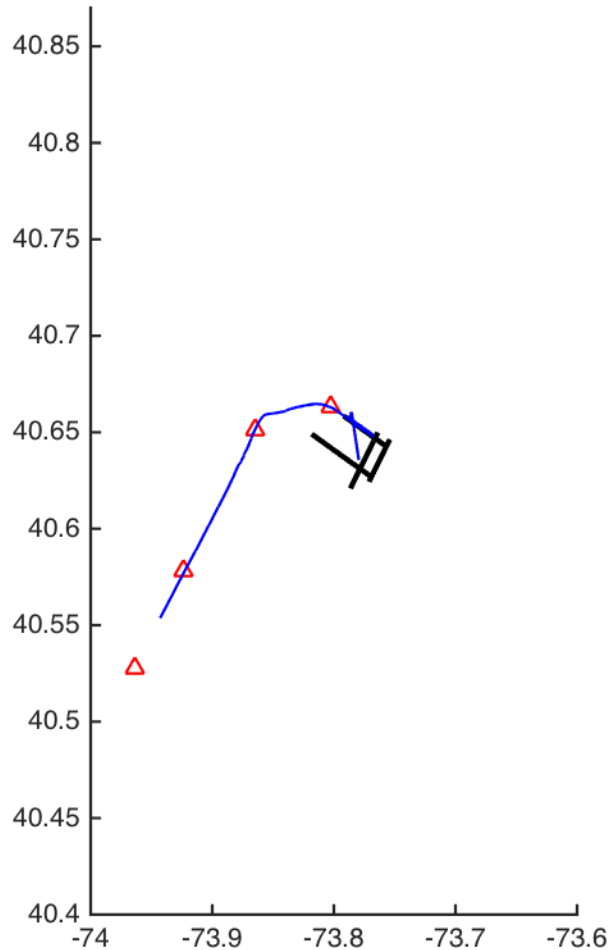


(B738)



B767 below glidepath

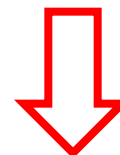
(B763) - 2016-02-03



Results

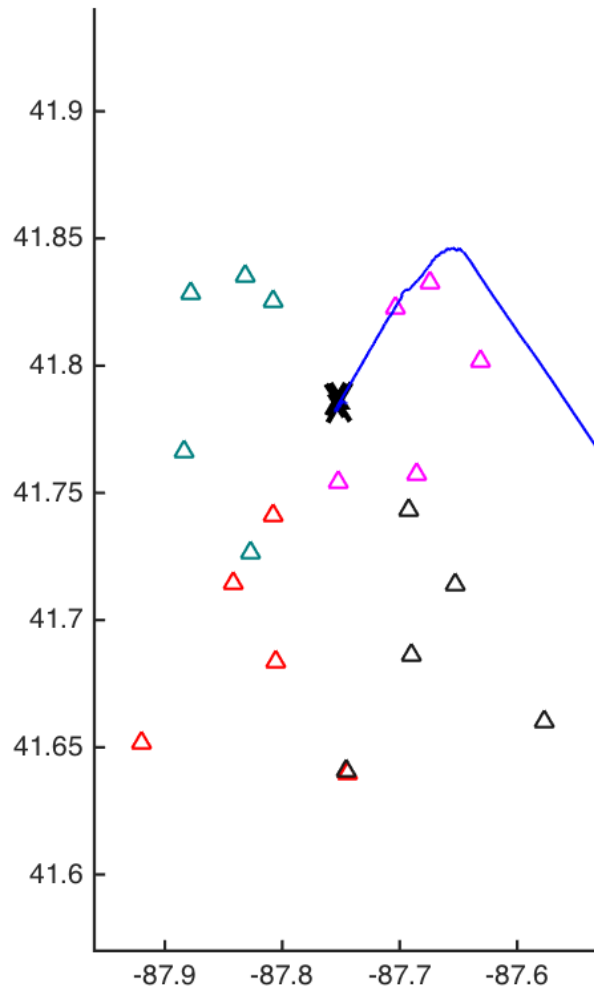
Approach Stability

- Approach stability was evaluated based on deviation from glidepath using the *Flight Safety Foundation* standards.

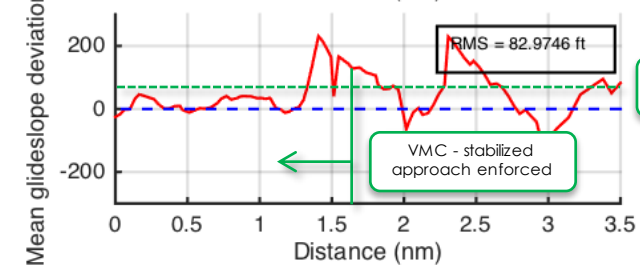
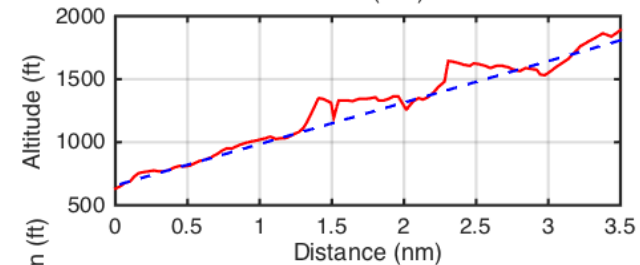
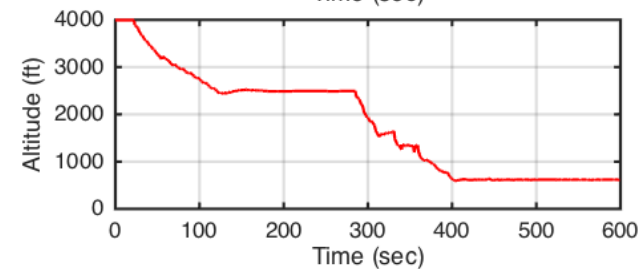
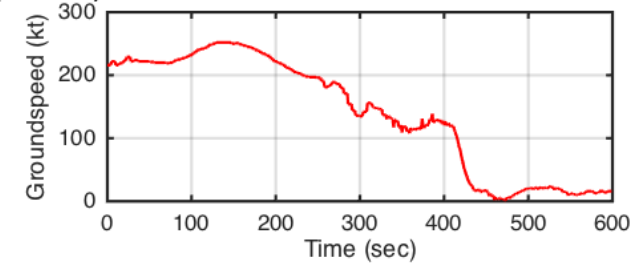


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IMC	1000 ft AGL	$V_{REF} \leq IAS \leq V_{REF} + 20 \text{ kt}$	$\pm 120 \text{ ft from glideslope (one dot deviation)}$	1000 ft/min

Example of Unstabilized Approach



(B733)



60 ft - maximum allowed VMC altitude deviation

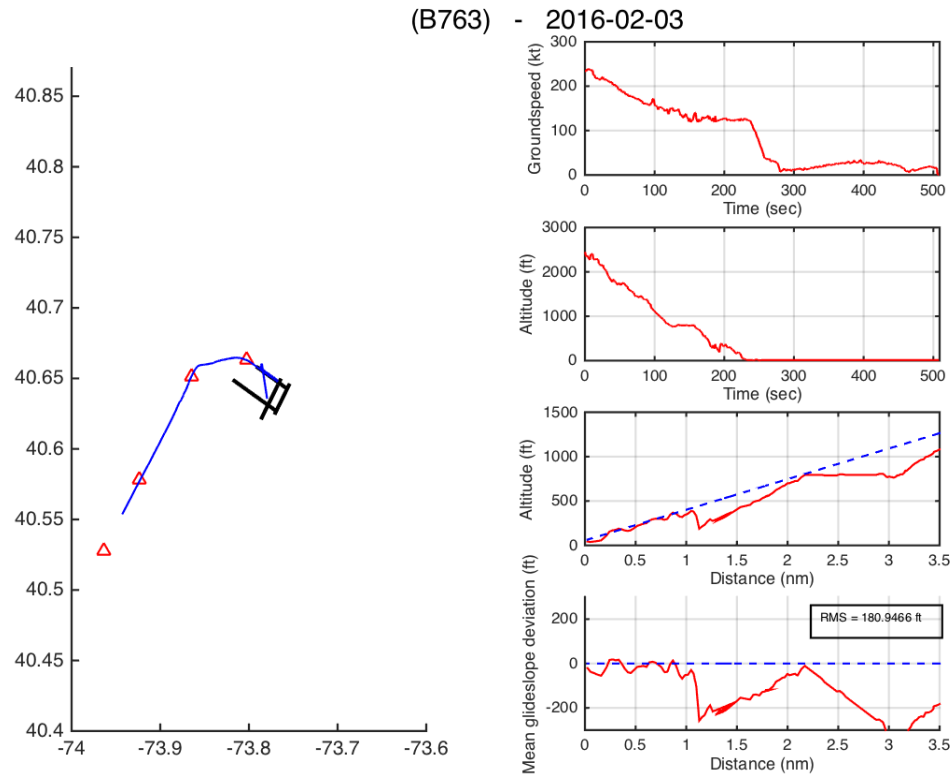
Results: Approach Stability

- Looked at 4,702 approaches in detail and analyzed their stability.
- Applying the Flight Safety Foundation standards for glidepath deviation yields the following numbers:

Approach type	Unstable approaches	Total approaches	Percentage unstable
RNP	3	340	0.88%
Non-RNP (ILS, Visual, VOR)	38	4,362	0.87%

Results: Dangerous Approaches

- Only one dangerous approach was observed (B767 landing at JFK). This was a non-RNP approach flown at night and likely without vertical guidance.



Conclusions

- No evidence of improved approach stability on RNP approaches has been found so far while applying the Flight Safety Foundation standards.
 - 381 RNP approaches were analyzed.
- **Hypothesis:** RNP is more likely to provide safety benefits in IMC if airport has no precision approach. Vertical guidance is key.
 - B767 case shows the risk of “dive-and-drive” approaches.
- RNP approaches may represent a more cost effective solution for approaches with vertical guidance compared to ILS from an **airport perspective**.
 - Operator must invest in additional aircraft equipment.

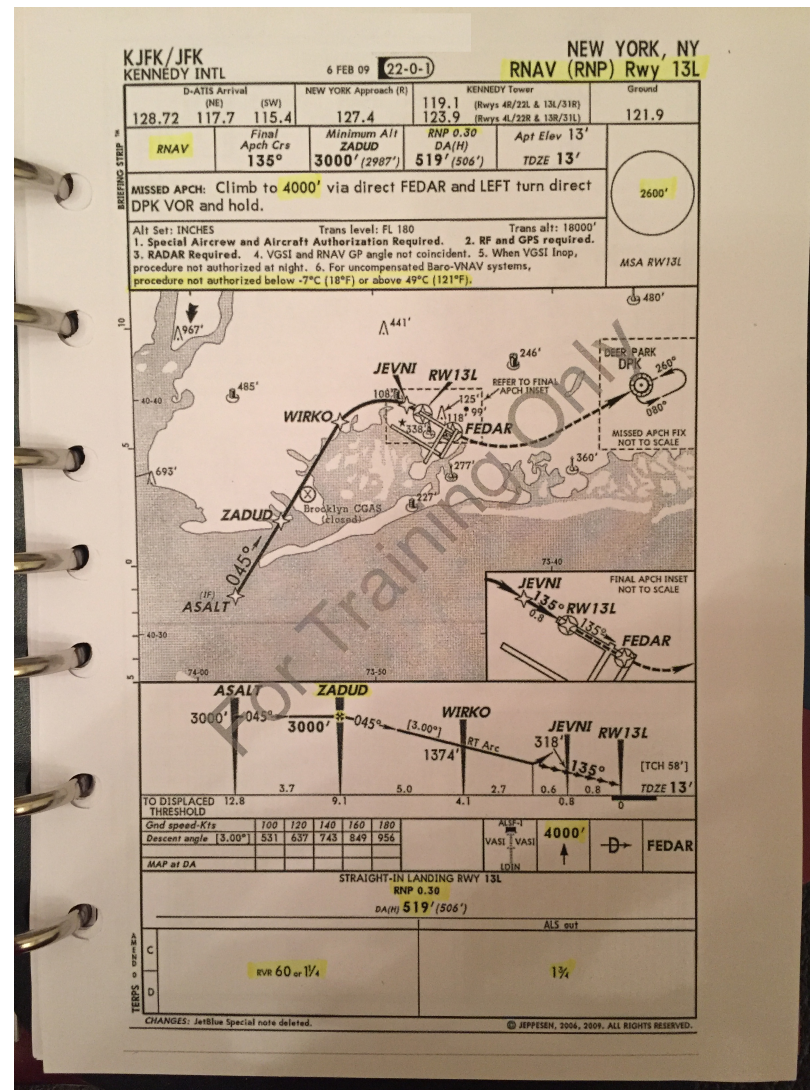
Future Work

- Run a large-scale safety analysis of approaches procedures in the NAS using much larger sets of ASDE-X data.
 - Last safety analysis of this type done in 1997.
- Investigate the use of more refined approach stability criteria.
 - e.g. being below glidepath can be considered more dangerous than being above glidepath.

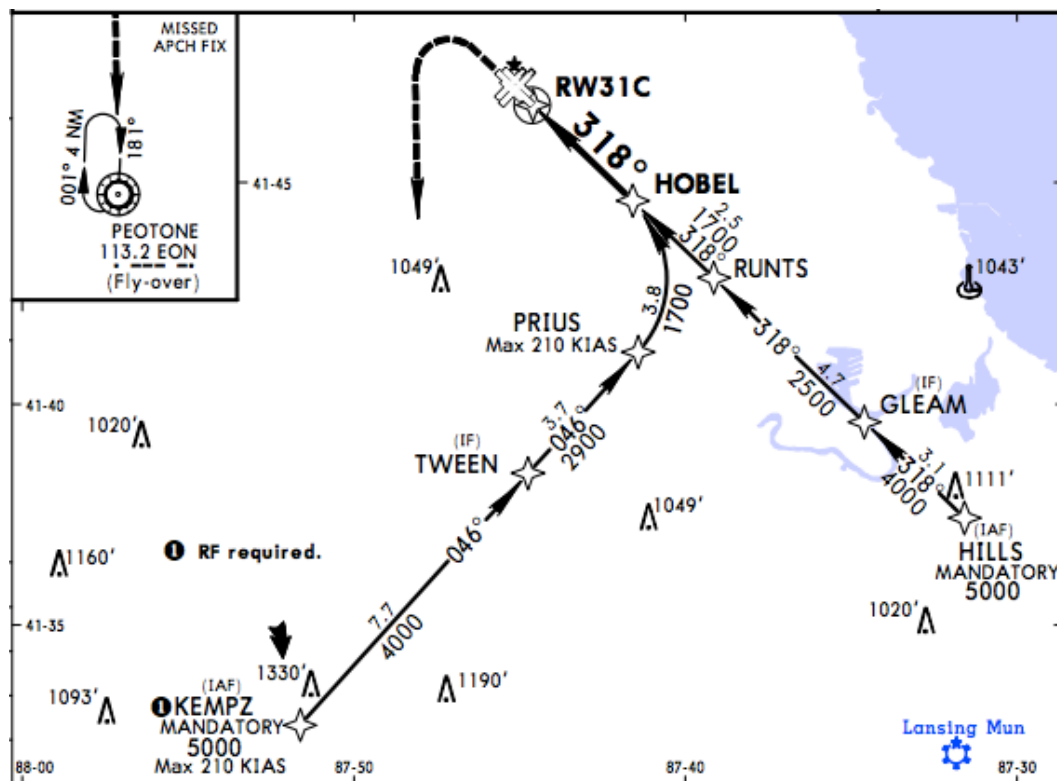
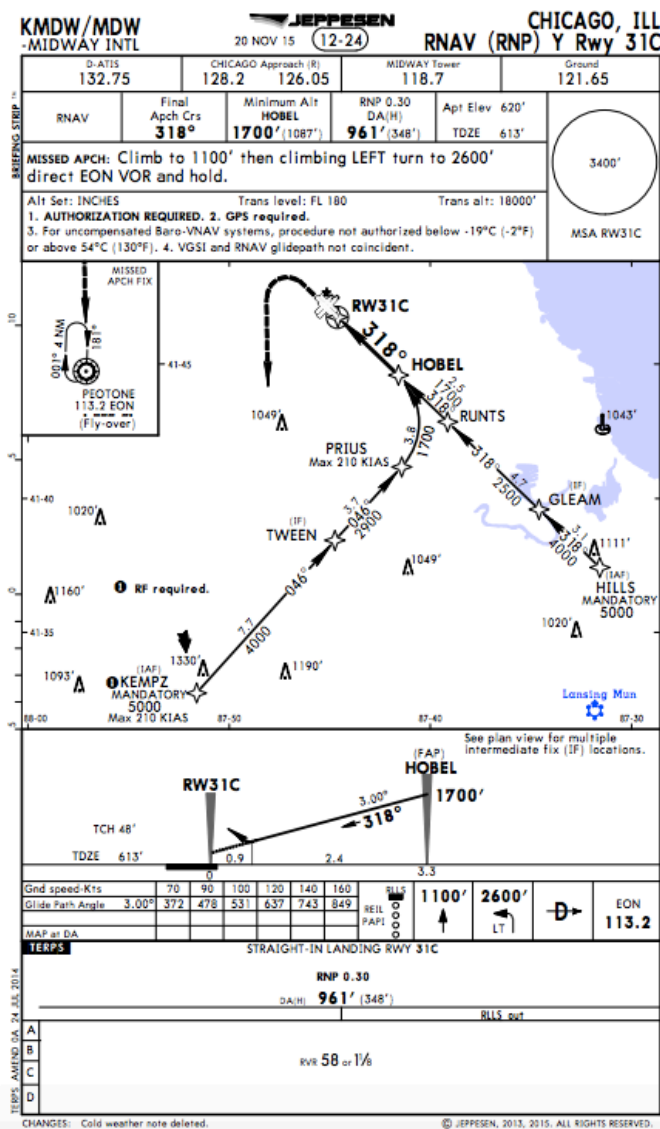


Charts

JFK RNP 13L



KMDW RNAV (RNP) Y RWY 31C



KMDW RNAV (RNP) X RWY 22L

